Technical Report No. 4

A NON-ADAPTED VEGETATION INTERFERES WITH SOIL WATER REMOVAL IN A TROPICAL RAIN FOREST AREA IN HAWAII

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ABSTRACT

A bunch grass species (Andropogon virginicus) from the North American continent was introduced to the island of Oahu, Hawaii in 1932. The grass began to spread. Today it forms the dominant grass cover in the rain forest zone, wherever the trees have been removed. Grass dominance is maintained by accidental fires. The grass goes into dormancy during the winter months. At that time, the shoots dry up and the grass cover turns into a mulch of straw, with few green blades remaining active. Also at that time, rainfall increases. Tropical trees (Eugenia cuminii, Mangifera indica, Psidium gujava, a.o.) in the same area remain green and productive during the period of increased rainfall. Transpiration was compared for the tree cover and grass cover on a land area basis. It was found that the trees are able to recirculate the incoming rain water into the atmosphere, while the grass cover is unable to remove excess soil water between rain showers. This results in increased runoff, erosion and slumping of the soil under the grass cover. In addition to forming a poor utilizer of the water resources available for primary production, the introduced grass causes damage to the landscape. Reforestation and fire protection is the answer to this problem.

INTRODUCTION

Most of the lowland vegetation in the Hawaiian Islands has been changed from its original state. This is particularly true for Oahu, which is the most urbanized of the six high Hawaiian Islands. Except for one area in the NW lowland of Oahu (Hatheway 1952), native forest vegetation has been replaced by introduced woody and herbaceous plants. Grass vegetation is now found in all climatic zones on Oahu (Kartawinata and Mueller-Dombois 1972), including the high rainfall areas in the mountains and on the windward (NE) side. In the middle-section of windward Oahu, tropical rain forest climate extends from the crest of the Koolau Mountain Range (from about 600 m) down to the sea (Fig. 1). Here, in the Kaneohe and Waikane area, coastal habitats are occupied by occasional rain forest groves of Hibiscus tiliaceus L. (Malvac.), Terminalia catappa L. (Combretac.), and Eugenia cuminii (L.) Druce (Myrtac.) (Richmond and Mueller-Dombois 1972). Inland, on the Humic Latosol clay up to about 50 m elevation, the area is used for cash-crop farming and residential purposes. From about 50 m to 250 m elevation on the same red clay soil, the vegetation is not forest, but variously disturbed grass cover, scrub-grass cover, savanna and parkland.

The dominant grass in this humid zone is Andropogon virginicus L. (broomsedge), which was introduced to Oahu as recently as 1932 from the Eastern United States (Whitney et at. 1939). In his descriptions of Oahu vegetation, Egler (1939, 1947) did not mention this grass. It has probably become naturalized as a community-structure forming plant only within the last 20 years. Andropogon virginicus is a perennial tall-bunch grass, which, once it has invaded an area after fire, begins to grow vigorously, continuously densifying its cover. It forms dry shoots that remain standing together with the active, green shoot portions. Throughout the year, Andropogon virginicus looks yellow because of the accumulated dead shoot

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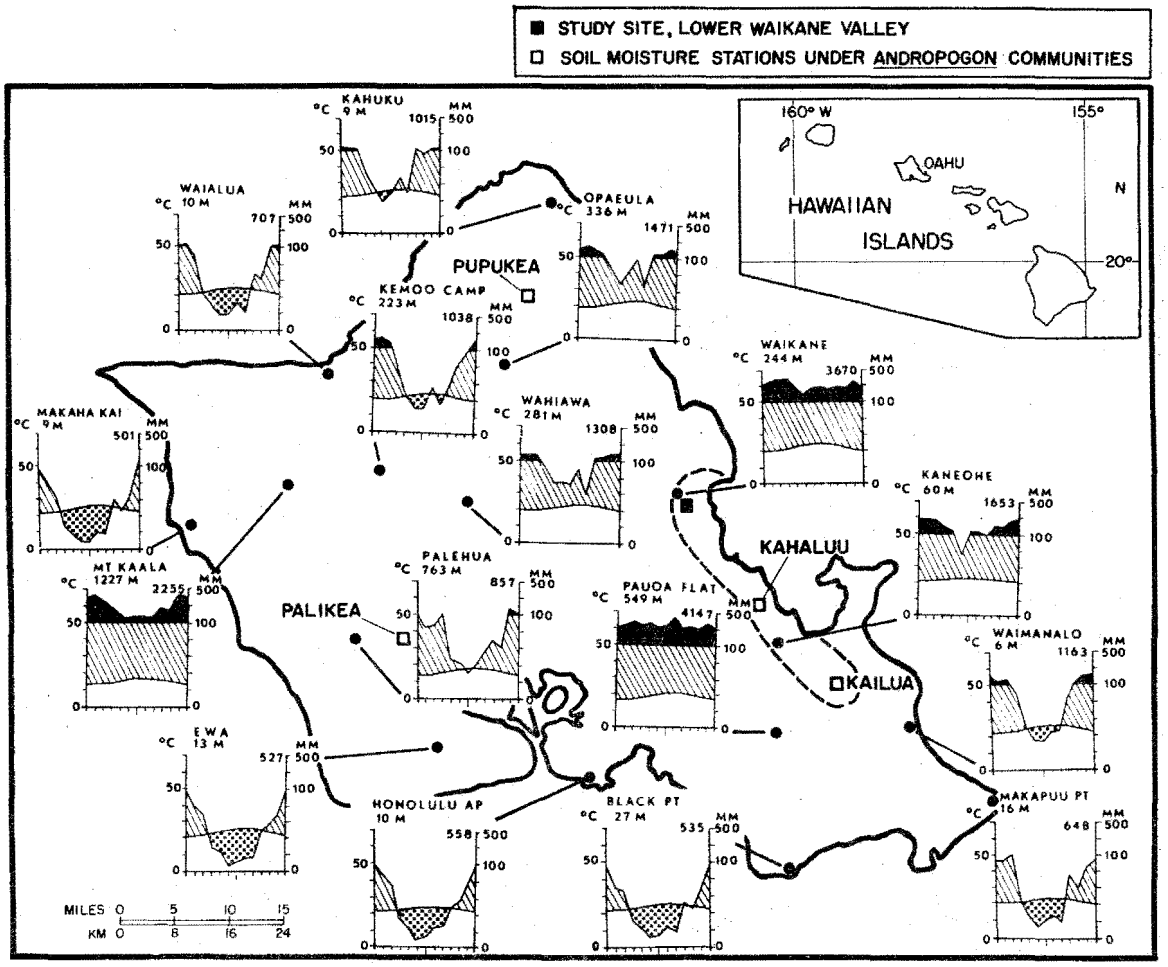

Fig. 1. Island of Oahu with study site and outline of surrounding area in which Andropogon virginicus forms grass communities in the lowland rain forest climate. Climate diagrams state mean annual rainfall and show curves of monthly mean rainfall (mm) with reference to the right-hand ordinate and monthly mean temperatures (^{o}C) with reference to the left-hand ordinate. Black fields show rainfall in excess of 100 mm per month, dotted fields indicate a drought period. Abscissa refers to months of year with July (longer vertical dash) in center. Climate diagram method after Walter (1957). Map from Kartawinata and Mueller-Dombois (1972).

portion. This is shed in part annually during the season of higher rainfall, October through April. At that time, the grass goes into partial dormancy, which is indicated by the drying-up of most of its current-year photosynthetic shoot portion. Only a central green shoot-core remains active during the winter-rains. The drying up of the greater shoot portion has the effect of a mulch or straw-cover on the soil. This mulch keeps the water in the soil, preventing not only effective transpiration but also soil evaporation at a time when rainfall is excessive.

This behavior does not apply to other introduced grasses that have become partially naturalized in the same climatic zone, such as Melinis minutiflora Beauv., Brachiaria mutica (Forsk.) Stapf, Rhynchelytrum repens (Willd.) C.E. Hubb., Setaria geniculata (Lam.) Beauv. and Paspalum orbiculare Forst. Also, it does not apply to the woody plants found in the area. These are all evergreens. They include Psidium guajava L. (Myrtac.) Eugenia cuminii, Mangifera indica L. (Anacardiac.), Schinus terebinthifolius Raddi (Anacardiac.) and others.

On the basis of this observation, an investigation of transpiration rates per unit land surface area was made in an Andropogon grass cover and an adjacent tree cover on the same soil (Humic Latosol) in lower Waikane Valley.

METHODS

A level to slightly coastward dipping ($< 5^{o}$ slope) area at 100 m elevation in lower Waikane Valley was selected, where Andropogon virginicus grass cover and tree cover occur side-by-side on the same red tropical lowland clay soil (locally called Humic Latosol, Cline et al. 1955). The tree cover is here composed of 8 to 14 m tall trees of Eugenia cuminii (Java plum) and Mangifera indica (mango), which grow in small clumps of 3-7 trees or isolated in a matrix of herbaceous and scrub cover in a parkland formation. Right next to the parkland formation occurs the

yellow dry-grass cover of Andropogon virginicus in part as pure grassland and in part as savanna with scattered isolated small (3-6 m tall) trees of Eugenia cuminii.

A sampling site for transpiration measurements and soil moisture analysis was established about 100 m apart in each, the Andropogon grassland and Eugenia-Mangifera parkland. A team of ecology students worked simultaneously at each sampling site on two sunny and windy October days (1970 and 1971). Subsequently, the daily march of transpiration was monitored on an overcast, windy day and on a sunny, calm day in February 1972.

Transpiration measurements by short-period weighing method

The short-period weighing or cut-shoot method has been described and evaluated by Stocker (1929), Walter (1960), Steubing (1965) and others.

The method makes use of the observation that green leaves or blades when cut from a growing plant maintain for a brief period the same rate of water-loss as occurring during transpiration in the natural environment at that time. This is true apparently, when there is no soil moisture stress. Under soil moisture stress, the rate of water loss may increase suddenly beyond the actual rate because of the release of tension. On the other hand, following removal, the stomata begin to close. A prerequisite for the reliability of this method is fast weighing immediately after the leaf or blade is removed from the growing plant. This requires setting up a transpiration balance right next to the plant in the field. As transpiration balances, we used torsion microbalances weighing to the nearest tenth of a milligram.

Each balance was set on a table into the stand of vegetation. A leaf or blade next to the table was cut and weighed within a few seconds. Then it was held for 2 minutes in the same position where it grew naturally and quickly thereafter reweighed. The time between weighings was measured with a stop watch. This

was repeated several times with a different leaf sample. The result of each sample was expressed in milligrams of weight-loss per original fresh weight in grams per minute ($mg \cdot g^{-1} \cdot min^{-1}$).

Several measurements of ambient air temperature were made during the experiments with an electrically ventilated Bendix psychrometer. Dry and wet bulb readings were recorded periodically, and from this, the relative humidity (RH), the vapor pressure deficit or saturation deficit (SD) and the dew points (DP) were calculated.

Soil moisture measurements

Soil pits were dug to a depth of $>$ 50 cm at each sampling site, and soil samples were collected in metal cans and weighed in the field. The samples were taken in three vertical rows about 40 cm apart in each pit. Downward in the soil pit, the samples were taken from the profile wall at 5, 25 and 50 cm depth. After field weighing, the soil samples were put into the drying oven for 48 hours at 105°C to determine their soil moisture percent by weight.

Additional soil samples were taken for determining the -15 bar* (permanent wilting percentage) and -.3 bar (field capacity) values with a Richards pressure plate apparatus (Richards 1947). Bulk density (BD) samples were obtained by removing soil of known volume from several places near the soil pits. The BD values were collected to convert the soil moisture weight percentages into millimeter of rain-water equivalent in the soil.

In a consecutive study of dry-grasslands all over Oahu (Kartawinata and Mueller-Dombois 1972), monthly soil moisture values were obtained from four Andropogon grass communities throughout an annual cycle.

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* 1 bar = .987 atm.

Analyses of foliage weight per square meter

Grass cover

Next to the soil pit, six square meter samples of grass cover were totally removed with grass shears. The grass litter and dry-blade fraction and the inflorescence stalks of Andropogon were separated and the green-blade fraction per square meter was weighed in the field.

Tree cover

The vertical projection of crown cover of five trees was measured with a meter tape on the ground. Two diagonal diameters (D_1 and D_2) were measured under each tree and the crown cover (CC) was obtained by the formula $CC = \left(\frac{D_1 + D_2}{4} \right)^2 \pi$.

The weight of foliage per tree was estimated from subsamples. Several branches, judged to be average, were removed and stripped of their leaves. The leaves of each sample-branch were weighed immediately in the field. The number of branches per tree were counted and their number was multiplied with the average foliage weight per branch to obtain the total weight of foliage per tree. The foliage weight per square meter was obtained by dividing the total foliage weight by the crown cover. Dry weights of both, grass and tree leaves, were determined subsequently after drying at $80^{\circ}C$ for 48 hours.

RESULTS

Rates of water loss per minute

Table 1 shows the water loss measured from cut grass blades and tree leaves on two October days at noon (1970 and 1971) when the NE trade winds blew with normal strength, about 10 to 15 mph. The weather was sunny with intermittent clouds and with brief, light showers in the afternoons. Such days are typical for

Table 1. Water loss from grass blades and tree leaves at mid-day (1-2 p.m.) on sunny days with normal trade winds (10-15 mph).

Date	Air temp. RH, SD, DP*	Evaporation Piché disc ($mg \cdot g^{-1} \cdot min^{-1}$)	Andropogon blades opened ($mg \cdot g^{-1} \cdot min^{-1}$)	Andropogon blades folded ($mg \cdot g^{-1} \cdot min^{-1}$)	Tree leaves Mangifera ($mg \cdot g^{-1} \cdot min^{-1}$)	Tree leaves Eugenia ($mg \cdot g^{-1} \cdot min^{-1}$)
Oct. 31, 1970	Dry bulb 26°C	11.6	16.5**	4.3	11.3	13.1 7.7
	Wet bulb 20.5°C	11.1	15.6	3.5	10.3	9.5 7.4
	RH 59%		9.8	3.3	9.1	9.2 6.9
	SD 8.1 mb		5.9	2.6	8.7	9.1 6.6
	DP 17°C					9.1 6.6
						5.8
	mean	11.4	12.0 ± 7.6***	3.4 ± 1.2	9.9 ± 1.9	8.3 ± 1.5
Oct. 23, 1971	Dry bulb 31.5°C	20.2	5.5	3.7	24.2 12.0	
	Wet bulb 24°C	18.8	5.3	3.7	22.1 11.5	
	RH 52%	18.1	5.2	3.5	14.6 9.3	
	SD 11.4 mb		4.9	3.1	13.9 1.3	
	DP 20°C			2.3		
	mean	19.0	5.2 ± .4	3.3 ± .7	13.6 ± 6.6	

* RH = Relative humidity
SD = Saturation deficit
DP = Dewpoint temperature

** Data are ranked from high to low for easier interpretation

*** the ± value is the 95% confidence limit of the mean as calculated from Snedecor's range statistics technique. If there is no overlap between two means plus or minus their confidence limits, the means are significantly different.

that time of the year. In addition, mean dry and wet bulb readings, dewpoint temperatures, relative humidity, and saturation (or vapor pressure) deficit and the evaporation rate from white Piché filter discs are shown.

At both times, most of the green Andropogon grass blades were completely folded. But, a few partially opened blades were also encountered. The open blades showed higher rates of water loss. In fact, the two first values listed in Table 1 under Andropogon blades, opened, were the highest recorded on that day. They exceeded even the free evaporation recorded from the Piché discs. This difference may be attributable to the fact that the green blades have a higher heat potential than the white discs, and the experiment was carried out in the bright sun. In comparing the rates of the opened grass blades with tree leaves, there is no significant difference between their water loss and that of the tree leaves on October 31, 1970. However, on October 23, 1971, the water loss of opened Andropogon blades was less than half that of the tree leaves. This can be attributed to the difficulty in finding opened grass blades on that day. Nearly all of the grass blades were folded on that day and the "opened" category on October 23, 1971 represents only partially opened blades.

The individual sample values in Table 1 are ranked from high to low to show the range of values, which is rather large in some sets. Even with great care, to avoid experimental errors, individual values may scatter quite considerably. Among tree leaves in particular, a few may have closed stomata. This was probably the case with the lowest value of 1.3 $mg \cdot g^{-1} \cdot min^{-1}$ for one of the Mangifera leaves (Oct. 23, Table 1). Therefore, readings have to be repeated several times. However, the mean values, shown in Table 1 seem useful approximations. Except for the opened blades on October 31, 1970, the grass blades showed significantly lower rates of water loss than the tree leaves. The water loss of the tree leaves did

not differ significantly among the two tree species.

Green shoot and foliage weights per square meter

Table 2 shows the green-blade fresh weight per square meter in six samples of the Andropogon grass community. Samples 1 and 2 were harvested in October 1969, samples 3 and 4 in October 1970 and samples 5 and 6 in October 1971. The samples were taken by a different group of students each in different places of the same grass community. The values were always below 1 kg/m^2 and the mean of .577 kg/m^2 is probably quite representative. The green blade fraction can be expected to decrease during the winter months and to increase during the summer months, when Andropogon resumes full activity. There is also a change with time after a fire. In the first year, there is very little grass litter. The grass litter increases with the years after a fire (Kartawinata and Mueller-Dombois 1972). The community sampled had not been burned for at least three years prior to 1969. The successive increase in litter fraction in the years after a grass burn may also have an effect on reducing the green-blade fraction. This has not yet been measured.

Table 3 shows the foliage weight per square meter of two evergreen tree species (Eugenia cuminii and Mangifera indica) as obtained through estimation from weighed subsamples. Since the weight per square meter did not differ significantly between the two species, an overall mean was calculated, which comes to 2.24 kg/m^2. Therefore, the green foliage mass per square meter of the tree cover was about 4 times that of the grass cover on the same habitat. The difference is statistically significant.

Water loss per unit ground area from vegetation covers

Table 4 shows the water loss from the grass cover and tree cover based on

Table 2. Grass cover fresh weight in kilograms per square meter in October

Sample No.	Total standing crop	Green blades*	Infloresc. stems	Dry blades and litter
1	2.219	.580	.189	1.450
2	1.729	.240	.100	1.389
3	—	.650	.350	—
4	—	.350	.420	—
5	—	.949	—	—
6	—	.695	—	—

Mean weight = .577 kg/m^2 green blades ($\pm$ .284 confidence limit)
* Dry weight = 35% of fresh weight

Table 3. Green foliage weight of trees per square meter

Tree No.	Species	Weight estimate* (kg)	Crown cover (m^2)	Weight per m^2 (kg)
1	Eugenia	48	28.3	1.70
2	Eugenia	27	12.6	2.14
3	Mangifera	120	42.6	2.82
4	Mangifera	120	67.4	1.78
5	Mangifera	196	70.6	2.78

* Based on weighed subsamples
Mean weight = 2.24 kg/m^2 green foliage (± .57 confidence limit)
Dry weight = 44% of fresh weight

Table 4. Estimate of water loss from grass and tree cover*

Date	Type of foliage	Water Loss $g \cdot kg^{-1} \cdot min^{-1}$	$g \cdot m^{-2} \cdot min^{-1}$	mm/hour	Vegetation cover type
Oct. 31/70	Grass blades open	12.0	6.9	.4	grass cover
	Grass blades folded	3.4	2.0	.1	
	Mangifera	9.9	21.8	1.3	tree cover
	Eugenia	8.3	18.6	1.1	
Oct. 23/71	Grass blades open	5.2	3.0	.2	grass cover
	Grass blades folded	3.3	1.9	.1	
	Mangifera	13.6	30.5	1.8	tree cover

* Based on mean weight of green foliage

the mean transpiration rates and mean green foliage weights per square meter for each type of foliage investigated. The mean rates of water loss obtained in $mg \cdot g^{-1} \cdot min^{-1}$ were first converted to water loss in grams per square meter per minute. Since 1000 g water per square meter is equivalent to 1 mm of rain fall, the water loss via transpiration can be expressed in millimeters of rainfall-equivalent. This is done in Table 4 by stating each mean water-loss rate in mm water loss per hour.

The rates of water loss in millimeters shown in Table 4 refer to the water loss during the noon hour (between 1-2 p.m.) on two sunny and windy October days in a tropical oceanic climate.

The conversion of water loss per minute to rates of water loss per hour is quite realistic, since the rates per minute are based on values obtained within a one-hour period.

Daily water loss from grass and tree cover

For obtaining an estimate of water loss per day, it was necessary to measure transpiration rates during an entire day, from morning to evening. This was done on two days in February 1972 following an extended period of rain.

Fig. 2 shows the average water-loss curves obtained on each of these two days. The daily curves for the dominant community-forming tree (Eugenia cuminii) and grass (Andropogon virginicus) are shown in relation to the evaporation curve as measured from white Piché filter discs. The plotted values are the means of always 5 readings, except for the evaporation values that are based on 2 readings each. The individual readings are shown in Appendix 1 and 2 together with the same environmental measurements as stated in Table 1.

Fig. 2a portrays the water-loss curves on an overcast, windy (15-20 mph) day.

The water loss of Eugenia on that day was erratic, but generally high in the morning through the early afternoon (about 10-20 $mg \cdot g^{-1} \cdot min^{-1}$). The rate only decreased towards the evening (to below 5 $mg \cdot g^{-1} \cdot min^{-1}$), when it fell below the evaporation curve. In contrast, the evaporation curve followed an almost straight-line trend. Thus, the water loss from Eugenia leaves was quite independent of the evaporation rates as measured from Piché discs. This may be attributable to the wind. Both the Piché and tree leaf readings were taken between 1.5 and 2 m height, but the Piché discs were held steady, while the tree leaves were allowed to shake in the wind as they did just before measurement on the branches. The water-loss curve of Andropogon blades remained below that of the evaporimeter discs and it showed only little variation throughout the day. The lower rate can be attributed to the low position of the grass shoots at 25-30 cm above the ground, where the wind velocity was much reduced. The absence of a distinct peak of water loss during most of the day can be attributed to the lack of insolation on that day. This is seen when comparing Fig. 2a to 2b.

Fig. 2b shows the water-loss curves on a sunny, calm (0-3 mph) day. On this day, all three curves follow more or less the usual pattern with a peak of water loss between 11 and 12 hours (near noon). Such unimodal trends are typical for plants growing without soil water stress on warm, sunny days (Müller-Stoll 1935, Steubing and Wilmanns 1962, Mooney, Brayton and West 1968). Evaporation was clearly the highest followed by water loss from tree leaves and then from grass blades. The lower water loss from the grass blades was not caused by folding as in the earlier instances (October) because the blades were opened on both days. On the sunny day, the lower rate could also not be attributed to a lesser wind velocity near the ground, because there was hardly any wind. Instead, the lower rate was probably caused by the almost vertical position of the grass blades.

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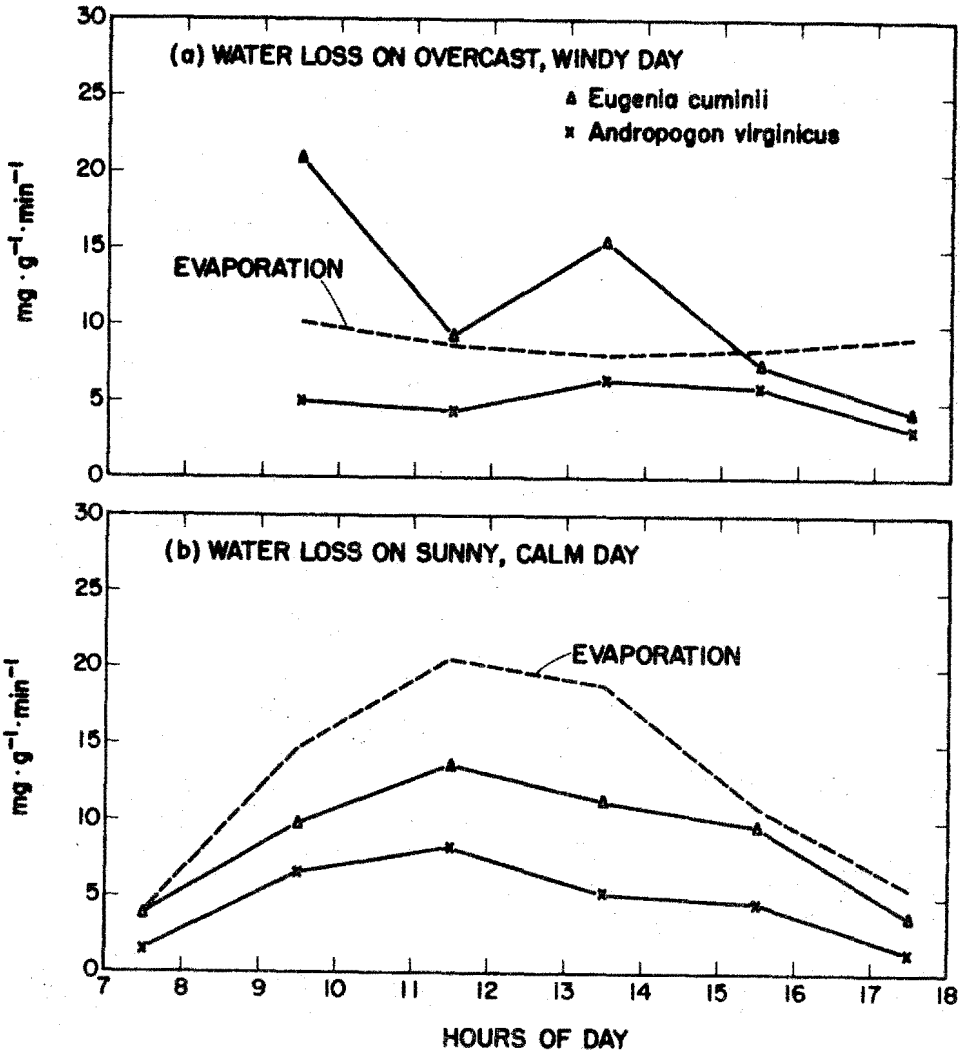

Fig. 2. Daily march of water loss from grass blades (Andropogon) and tree leaves (Eugenia) in relation to evaporation from white Piché filter paper discs.

This allows for comparatively less heating of the leaf tissue from insolation than the more horizontal position assumed by the Eugenia tree leaves. Therefore, while there may be additional physiological and morphological reasons for the grass blades to lose less water than the tree leaves, their reduced water loss, as observed on all days, can be attributed to three main factors: (1) folding of blades on sunny and windy days (as noted in the October experiments), (2) near vertical position of grass blades, which prevents strong heating on sunny days when wind velocity is low, (3) protection from strong wind, because of position near the ground, where wind velocity is reduced in comparison to the height of tree crowns.

The daily rate of water loss was calculated from the areas under the curves for a 12 hour period, from 6:30 - 18:30 hours. Fig. 2b indicates that water loss from grass blades and tree leaves may become insignificant near 18 hours when the sun goes down, and it only increases to significant amounts near 7 hours in the morning. Even on a windy overcast day (Fig. 2a), water loss from the plants decreased towards the evening, when evaporation remained still high. This shows that water loss from plants during the night can be ignored because the stomata are probably mostly closed. In addition, the cooler night temperatures increase the relative humidity and decrease the saturation deficit so that the evaporative power will be very low as well.

The daily rates calculated in this way for 12 daylight hours are shown in Table 5.

Table 5. Daily rate of water loss from Andropogon and Eugenia foliage on two February days.

Date Weather	Type of foliage	Water loss during day $g \cdot kg^{-1} \cdot min^{-1}$	$g \cdot m^{-2} \cdot min^{-1}$	mm/hr	Daily rate mm
2-19-72	Grass blades	4.2	2.4	.14	1.7
overcast	Tree leaves	10.0	22.4	1.34	16.1
windy					

Table 5. Continued

Date Weather	Type of foliage	Water loss during day $g \cdot kg^{-1} \cdot min^{-1}$	$g \cdot m^{-2} \cdot min^{-1}$	mm/hr	Daily rate mm
2-21-72	Grass blades	4.3	2.5	.15	1.8
sunny	Tree leaves	8.8	19.7	1.18	14.2
calm					

Note that the water loss in millimeters per hour was found to be of similar magnitude to that in October (Table 4). That is, the water loss from the tree canopy was almost 10 times that of the grass cover.

DISCUSSION

Estimated water loss per month from grass and tree cover

It is of interest to convert the daily water loss from the two types of vegetation cover into a monthly value, because such a value can then be compared to the incoming amount of water in the form of monthly rainfall.

There are a few complications in such a conversion. Firstly, the day-to-day water-loss rate can be expected to vary with weather conditions. Secondly, the daily rate is certainly affected by the moisture content of the soil. Our soil moisture results showed that soil water was well above the permanent wilting percentage under both vegetation covers on the two October days. The soils were also wetted to field capacity on the two February days. However, this does not explain anything about periodic variation in soil moisture. This question will be discussed in a separate section below.

Of course, the stomata may close also during windy weather when soil moistures is adequate. That at least the latter form of stress condition occurred was shown by the fact that most of the Andropogon grass blades were folded on the October

days. Similarly, the stomata of the tree leaves were probably partly closed because other literature values for sclerophyllous evergreen trees are often somewhat higher (Walter 1971) than the mean values obtained here.

Variable weather conditions were already included in the experiment. Yet, inspite of these variable weather conditions, the daily rates of water loss were remarkably uniform. The two contrasting days in February were typical for the Hawaiian winter season on the windward side, so that it would seem reasonable even to average their daily rates. Much of the rainfall occurs during nights. However, there are a few days when it rains more or less all day long, and during the rainfall, there is, of course, no water loss.

To arrive at a reasonable estimate of monthly water loss, therefore, it would be necessary to know the hours of rainfall that occur during the day. Such a record was compiled (National Weather Service Honolulu 1972) for a windward station (Mauna Wili) with the same annual rainfall and that occurred at the same elevation as the sampling site. The record gives percent frequency of rain over .01 inches per hour of day on an annual basis for a period of 6 years. According to this record, rain showers occur for 35 minutes on an average day throughout the year on the windward side of Oahu. During the winter months, the amount will increase somewhat, and as a reasonable approximation, one may estimate that it rains about 1.2 hours out of 12 hours on the average. Thus, transpiration can be expected to occur 90% of the time during daylight, and the monthly rate of water loss can be assessed by multiplying the daily rate by 27. The monthly values derived in this way are shown in Table 6.

Table 6. Estimate of monthly water loss for grass and tree cover during rainy season, October through April.

Vegetation	Rate of water loss in mm per day	per month*
Grass cover	1.7 - 1.8	46 - 49
Tree cover	14.2 - 16.1	383 - 435

* daily rate times 27 (derived from .9 x 30)

Comparison to incoming amount of water

The amount of median monthly rainfall at the 100 m sample site was obtained from 25-year rainfall isohyets published on 12 maps of Oahu (Taliaferro 1959). The median monthly rainfall is tabulated below (Table 7).

Table 7. Median monthly rainfall for lower Waikane Valley at 100 m elevation.

Month	Amount (mm)	Month	Amount (mm)
January	200	July	100
February	200	August	125
March	210	September	125
April	150	October	150
May	100	November	220
June	85	December	250

Annual median rainfall 1,915 mm

A comparison of the monthly rainfall in the wetter months (from October through April) with the estimated monthly water loss for the grass cover in Table 6 (46-49 mm) shows that the Andropogon grass community cannot be expected to remove the excess soil water between shower activity. The capacity of the Andropogon grass cover is only about one third to one fifth that of what would be required.

In contrast, the capacity of trees to remove soil water (383-435 mm) is far greater than the amount of monthly rainfall. Their water removal capacity is about twice as great as the amount of incoming water. Of course, the actual water loss from the trees cannot exceed the incoming amount. The trees are expected to show lower rates on days when they have exhausted the soil water to near wilting percentage. For calculating the actual monthly rate of water loss, measurements would have to be done also on days with low soil water levels. However, this is not important for this comparison.

Monthly soil water under Andropogon grass communities

It may be argued that soil water is removed not only by transpiration, but also by direct soil water evaporation. Soil water evaporation was not measured in this study, but it can be assumed to be negligible under the closed grass cover of Andropogon communities. In this community, a few years after a fire, the grass cover is so dense that there is no exposed soil. Moreover, evaporation studies from bare Hawaiian latosols by Ekern (1966) have shown that evaporation from soils wetted to field capacity is only one third that of pan evaporation. Soil surface evaporation is reduced when the soil is still quite wet, already at extremely low tensions of .15 bar. Therefore, these clay soils tend to retain water effectively against evaporation, and this is attributed to their high aggregation. This is described as a "self-mulching" property in these tropical clay soils.

The assumption that soil water evaporation is insignificant is supported by the soil water diagrams. Fig. 3 shows the annual march of soil water at 25 cm soil depth under four Andropogon virginicus communities in four different rain forest areas on Oahu (from Kartawinata and Mueller-Dombois 1972).

The black fields show the amount of water in excess of field capacity. It can be seen that excess water occurred under Andropogon grass cover throughout the year at all four locations.

Fig 3.1 (Kailua) and Fig. 3.2 (Kahaluu) are the closest soil sampling stations to the study site in lower Waikane Valley (see Fig. 1). They are in lowland rain forest terrain. The other two soil water sampling stations were in montane rain forest terrain. The dotted lines below the black fields give the field capacity (FC) as determined from the -.3 atm value in Richard's pressure plate apparatus. Water held at FC varied in the two lowland tropical clay soils from < 100 to > 120 mm (Fig. 3.1 and 3.2). At permanent wilting percentage (as determined from

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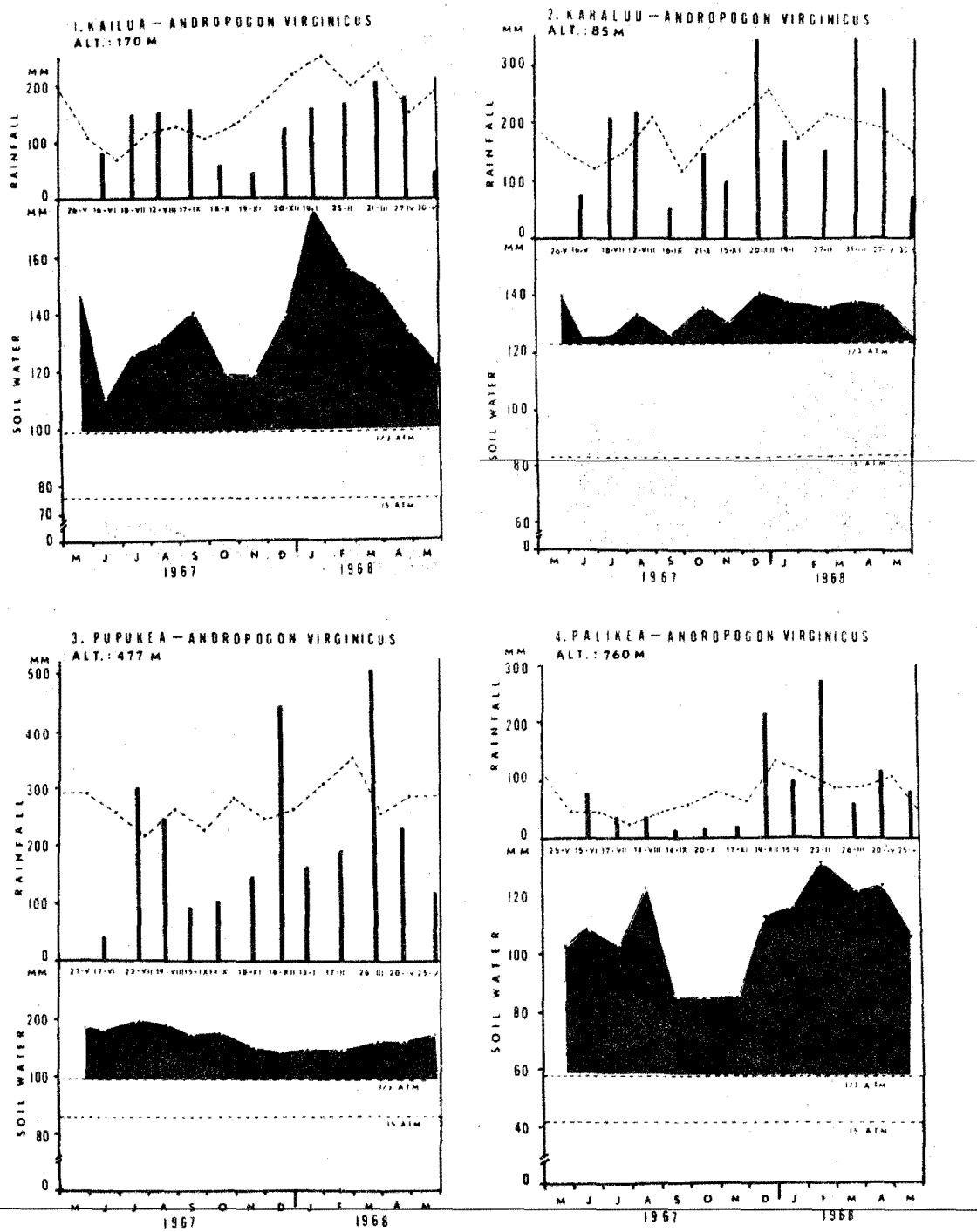

Fig. 3. Soil water at 25 cm depth under four Andropogon virginicus grass communities showing monthly amounts in mm for an annual cycle. Black fields show water in excess of field capacity (1/3 atm). The lower dashed line indicates the water content at permanent wilting percentage (15 atm). The black histogram bars show amount of rainfall (mm) collected at dates shown. The upper dashed line across the bars indicates 25-year median rainfall at that location. For locations, see Fig. 1.

the -15 atm value, the lower dotted line on each graph), the water held is about 80 mm. Thus, the range of available water, as conventionally defined, varies only from 20-40 mm, a rather narrow range. The soil water graphs also show the amount of mean monthly rainfall (dotted curves) and the actual monthly rainfall (black bars) that occurred during each month of soil moisture sampling.

CONCLUSIONS

The presence of excess water under Andropogon grass communities on rain forest soils throughout the year shows that water removal from this grass cover is insufficient not only during its period of partial dormancy, but even during the more productive summer season. The reason can be attributed to the perennial presence of dry shoots and litter that cover the soil surface and thus prevent both soil evaporation and effective transpiration. In the montane rain forest terrain at Pupukea, Andropogon-covered sites were swampy year-round.

In contrast, a closed evergreen tree cover will utilize most of the soil water that becomes available in the root zone in the lowland rain forest soil. The capacity to recirculate water from soil exceeds the incoming amount throughout the period of increased rainfall, from October through April. This is so, provided that the monthly rainfall does not occur in one or two days, which it does not. Multiplication of the daily rate of water loss from a few leaf samples with the foliage-weight of the entire crown is admittedly an oversimplification. A proportion of the leaves of any of the tree crowns was overlapping with other leaves, and it can be expected that the more hidden and shaded leaves do not transpire as much as the outer, exposed leaves. However, the leaves in the upper crown may lose more water than those of the lower crown which were measured in these experiments. Moreover, epidermal water loss from branches was ignored and so was the water loss from the bushy and herbaceous undergrowth. The derivation of absolute values

would require very much more work. However, while the water-loss values are only approximations, it is not necessary in this case to wait for a detailed investigation to realize the implications.

The comparison implies that there is a much greater monthly runoff to be expected from the areas covered with Andropogon grass because water does not penetrate readily into a soil that is full of water. Instead, it backs up soon after the start of a shower and then water runs over the surface to lower areas. This causes accelerated erosion. Evidence for this in the form of slumps on steeper slopes and deeply cut erosion channels through the grassland is plentiful in the lowland terrain.

Therefore, in addition to being a poor utilizer of the productive capacity of the rain forest habitat, the introduced Andropogon virginicus grass causes damage to the landscape and probably adds to the undesirable silting-up process in the Kaneohe Bay area on Oahu.

The answer to the problem is reforestation with climatically adapted evergreen species and fire protection.

A follow-up study on the quantitative significance of this relationship is planned by mapping the extent of the Andropogon grass cover, by measuring its seasonal and successional dynamics, by monitoring periodic variation of soil water under the tree cover for at least a year simultaneously with the grass cover and by measuring interception and runoff directly for both vegetations.

Appendix 1. Water loss from grass blades and tree leaves on an overcast windy day ($mg \cdot gram^{-1} \cdot min^{-1}$), February 19, 1972.

Time	Piché (1.5 m high)	Andropogon (25-30 cm high)	Eugenia (1.5-2 m high)
9 - 10 h	12.3	8.5	27.6
Dry bulb 22.5°C	8.3	5.9	26.2
Wet bulb 18.5°C		4.0	25.3
RH 66%		3.1	18.4
SD 6.1 mb		2.4	6.3
DP 16°C			
11 - 12 h	10.8	4.5	10.2
Dry bulb 21.5°C	6.8	4.2	8.0
Wet bulb 18.5°C			
RH 74%		only two values each because	
SD 4.9 mb		of light rain shower at this	
DP 17°C		time	
13 - 14 h	10.2	9.4	32.0
Dry bulb 20.5°C	5.6	9.3	25.2
Wet bulb 18.0°C		5.6	12.0
RH 86%		5.1	6.2
SD 2.9 mb		2.4	2.3
DP 18°C			
15 - 16 h	8.5	7.8	12.8
Dry bulb 20.5°C	8.0	6.3	9.9
Wet bulb 18.5°C		6.1	8.5
RH 91%		5.2	2.6
SD 1.9 mb		4.8	2.2
DP 19°C			
17 - 18 h	9.7	5.2	8.4
Dry bulb 20.5°C	8.6	4.8	5.2
Wet bulb 17.5°C		3.5	3.6
RH 71%		2.5	2.8
SD 3.8 mb		0	1.5
DP 15°C			

Appendix 2. Water loss from grass blades and tree leaves on a sunny calm day ($mg \cdot g^{-1} \cdot min^{-1}$), February 21, 1972.

Time	Piché (1.5 m high)	Andropogon (25-30 cm high)	Eugenia (1.5-2 m high)
7 - 8 h	5.1	4.3	9.0
Dry bulb 18.5°C	2.0	1.5	3.9
Wet bulb 18.0°C		1.3	3.7
RH 95%		.7	1.5
SD 1.0 mb		.4	1.2
DP 18°C			
9 - 10 h	17.2	11.0	16.3
Dry bulb 23°C	12.2	7.3	9.8
Wet bulb 21°C		6.2	8.8
RH 83%		4.3	7.9
SD 3.9 mb		3.5	6.1
DP 20°C			
11 - 12 h	26.6	14.4	18.6
Dry bulb 25°C	14.1	9.3	15.8
Wet bulb 21°C		7.5	14.9
RH 68%		5.3	11.2
SD 7.0 mb		4.0	7.3
DP 19°C			
13 - 14 h	23.6	7.9	16.1
Dry bulb 27°C	14.2	6.9	11.7
Wet bulb 22.5°C		5.0	11.3
RH 66%		4.4	9.6
SD 8.0 mb		2.4	7.6
DP 20°C			
15 - 16 h	13.8	6.0	13.5
Dry bulb 24.5°C	7.8	5.0	11.2
Wet bulb 20.0°C		4.4	10.2
RH 64%		4.2	8.5
SD 7.1 mb		3.5	5.4
DP 17°C			
17 - 18 h	6.9	2.5	7.5
Dry bulb 23.5°C	4.1	1.6	4.2
Wet bulb 20.0°C		1.4	3.2
RH 71%		1.3	2.9
SD 6.0 mb		0	0
DP 18°C			

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REFERENCES

Cline, M. G. et al. 1955. Soil survey of the Territory of Hawaii. U.S.D.A. in cooperation with Hawaii Agric. Exp. Sta. Soil Survey Series 1939, No. 25: 644 pp. + maps.

Egler, F. E. 1939. Vegetation zones of Oahu, Hawaii. Empire Forestry Journal 18: 44-57.

_____. 1947. Arid southeast Oahu vegetation, Hawaii. Ecol. Monographs 17: 383-435.

Ekern, P. C. 1966. Evaporation from bare Low Humic Latosols in Hawaii. J. of Appl. Meteor. 5(4): 431-435.

Hatheway, W. H. 1952. Composition of certain native dry forests: Mokuleia, Oahu, T.H. Ecol. Monographs 22: 153-168.

Kartawinata, K. and D. Mueller-Dombois. 1972. Phytosociology and ecology of natural dry-grass communities on Oahu, Hawaii. In press. Reinwardtia. (based on Ph.D. Dissertation of same title by Kuswata Kartawinata, University of Hawaii, Honolulu, 302 pp.)

Mooney, H. A., Brayton, R. and M. West. 1968. Transpiration intensity as related to vegetation zonation in the White Mountains of California. Am. Midl. Naturalist 80(2): 407-412.

Müller-Stoll, W. R. 1935. Ökologische Untersuchungen an Xerothermpflanzen des Kraichgaues. Zeitschr. f. Bot. 29: 161-253.

National Weather Service Honolulu. 1972. Unpublished manuscript, courtesy of Mr. Saul Price, Regional Climatologist, U.S. Dept. of Commerce, National Weather Service Pacific Region, Honolulu, Hawaii.

Richards, L. 1947. Pressure-membrane apparatus-construction and use. Agric. Engineering 28 (10).

Richmond T. de A. and D. Mueller-Dombois. 1972. Coastline Ecosystems on Oahu, Hawaii. In press. Vegetatio.

Steubing, L. 1965. Pflanzenökologisches Praktikum. Methoden and Geräte zur Bestimmung wichtiger Standortsfaktoren. Verlag Paul Parey, Berlin u. Hamburg. 262 pp.

_____ and O. Wilmanns. 1962. Wasserhaushaltsuntersuchungen in Rasengesellschaften des Kroatischen Karstgcbietes. Zeitschr. f. Botanik 50 (1): 34-51.

Stocker, O. 1929. Eine Feldmethode zur Bestimmung der momentanen Transpiration and Evaporationsgrösse. Ber. Deutsch. Bot. Ges. 47: 126-136.

Walter, H. 1957. Wie kann man den Klimatypus anschaulich darstellen? Umschau in Wiss. u. Tech. Heft 24: 751-753.

_____. 1971. Ecology of tropical and subtropical vegetation. Oliver and Boyd, Edinburgh. 539 pp.

_____. 1960. Grundlagen der Pflanzenverbreitung. 1. Teil. Standortslehre. Eugen Ulmer Verlag, Stuttgart. 566 pp.

Whitney, L. D., Hosaka, E. Y. and J. C. Ripperton. 1939. Grasses of the Hawaiian ranges. Hawaii Agric. Expt. Sta. Bull. No. 82. 144 pp.